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Processing biomass in a central location with the separator - shear system

A.W.J. Sinclair

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Processing Biomass in a Central Location with the Separator-shear System

A. W. J. Sinclair *

FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

201 — 2112 West Broadway
Vancouver, B. C.
V6K 2C8

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Canadian Forestry Service
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V8Z 1M5

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FOREWORD

ENFOR is the acronym for the Canadian Government's ENergy from the FORest (ÉNergie de la FORêt) program of research and development aimed at securing the knowledge and technical competence to facilitate in the medium to long-term a greatly increased contribution from forest biomass to our nation's primary energy production. This program is part of a much larger federal government initiative to promote the development and use of renewable energy as a means of reducing dependence on petroleum and other non-renewable energy sources.

The Canadian Forestry Service (CFS) administers the ENFOR Biomass Production program component which deals with such forest-oriented subjects as inventory, harvesting technology, silviculture and environmental impacts. (The other component, Biomass Conversion, deals with the technology of converting biomass to energy or fuels, and is administered by the Renewable Energy Branch of the Department of Energy, Mines and Resources). Most Biomass Production projects, although developed by CFS scientists in the light of ENFOR program objectives, are carried out under contract by forestry consultants and research specialists. Contractors are selected in accordance with science procurement tendering procedures of the Department of Supply and Services. For further information on the ENFOR Biomass Production program, contact ...

ENFOR Secretariat
Canadian Forestry Service
Ottawa, Ontario
K1A 1G5

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Abstract

A separator-shear system for upgrading sortyard debris to usable biomass for energy was tested at the B.C. Forest Products' Shoal Island sortyard. The system proved reliable and efficient and is capable of processing as much as 211 tonnes per shift on an operational basis. Processing costs were $5.40 per tonne. A payback period of 2.5 years was estimated. Operational testing on logging residues indicated a much lower productivity (54.7 tonnes per shift) and correspondingly higher costs.

Résumé

Des essais d'un dispositif séparateur-cisaille pour la valorisation des débris de triage en biomasse utilisable pour la production d'énergie ont été effectués a l'emplacement de triage de B.C. Forest Products à l'île Shoal. En conditions opérationnelles, le dispositif s'est révélé à la fois fiable et efficace, produisant 211 tonnes par quart de travail. Les coûts de traitement se sont élevés à 5,40$ la tonne. Le délai de récupération a été estimé à 2,5 ans. Un essai opérationnel avec des résidus d'exploitation forestière a indiqué une productivité beaucoup plus faible (54,7 tonnes par quart de travail) et des coûts proportionnellement plus élevés.

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Summary

Field tests were conducted on a separator-shear system at B.C. Forest Products' Shoal Island sortyard in the winter of 1983. Although a short trial was made on logging residues, the majority of material processed was sortyard debris. After processing in the separator-shear system, the material was transported to one of two hog mills where it was made into hog fuel and then burned in a cogeneration boiler. The productivity and costs, as well as energy consumption for the system, were determined. With installation of a feed-monitoring system and modifications to the disc separator, the separator-shear system will be suitable for commercial application.

The Nicholson biomass shear, in its present stage of development, is a reliable, precommercial production prototype which achieved 86 percent utilization in field tests. A utilization of 85 percent or higher is likely on an operating basis.

The separator-shear system processed sortyard debris at a rate of 211 tonnes per eight-hour shift during field trials and should achieve this on an operational basis. At this rate, the operating, maintenance and ownership costs of the system are $5.40 per tonne of processed material. This is less than conventional disposal costs of $7.00 to $7.50 per tonne.

The economics of a system which would process sortyard debris, transport the sheared material to a hog mill 60 km distant, transport the waste fines to a landfill 5-10 km distant and process the sheared debris into hog fuel, are summarized in Table S1.

Transportation costs to the hog mill are significant and if the hog mill is closer to the yard, the economics would improve. A payback of 2.5 years is attractive and should ensure the commercial acceptance of this system.

Processing sortyard debris in the separator-shear

Table S1. Summary of economics

Hog Fuel Production	33 400 tonnes/year
Waste Production	8 200 tonnes/year
Separating-shearing Cost	$224 640 year
Transport to Hog Mill Cost	$255 510 year
Waste Disposal cost	$ 40 590 year
Hogging Costs	$140 280 year
Total Costs	$661 020 year
Debris Disposal Savings	$273 800 year
Oil Savings	$576 800 year
Total Savings	$841 600 year
Net Benefit	$180 580 year
Capital Investment In System	$450 000
Payback	2.5 years

system improved its value as feedstock for hogged fuel. Separation reduced ash and moisture content and shearing reduced the range of sizes. Oversize material was eliminated and the sheared material flowed better in the hog mill's conveyors and through the hog mill.

In a short trial, dry logging residues were processed through the separator-shear. Although set to shear a nominal length of 46 cm, slippage between the feedrolls and the residue resulted in the majority of the pieces being 15 to 30 cm long. Field test productivity was 54.7 tonnes per shift. Operational utilization of 85 percent would result in a production rate of 66.7 tonnes per shift and if the material is sheared to a nominal 92 cm length for drum-chipper hog mills, the production rate could reach 133.6 tonnes per shift.

There are two modifications that will be necessary in a commercial model. The first is to include a scanning device at the outlet of the shear to ensure that the required length of debris has protruded through the shear opening before it is cut. The second is to design the disc separator so that the number of shafts, the rotation speed of the discs and the disc and shaft spacing is adequate to give more efficient separation at the production rate of the system.

Energy consumption averaged 110.6 Mj per tonne of material processed both for dry logging residues and sortyard debris. Energy consumption for transportation varied from 49.5 Mj to 124.9 Mj per tonne of mateial processed and reflected differences in transportation distances and load size. The net heating value of the hogged, sortyard debris was 4580 Mj per tonne.

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INTRODUCTION

In the dryland sortyards on the coast of British Columbia, approximately five percent of the solid wood volume processed becomes wood waste. The waste is composed of bark, branches, logs, slabs, chunks, rocks, metal, sand and water. Disposal can cause environmental problems and become costly. It is difficult to handle and transport with conventional equipment, and is usually disposed of by landfill or burning. Only a few of the approximately 90 coastal sortyards utilize the wood waste for its energy potential as hog fuel.

An economic study performed by the Forest Engineering Research Institute of Canada (FERIC) indicated that processing sortyard debris into hog fuel was economically attractive if there was an existing hog mill facility nearby and there was a demand for hog fuel. However, sortyard debris is difficult to process in conventional hog mills and conveyor systems and when processed produces a dirty, wet hog fuel. These findings led to the development of the separator-shear system. The shear portion would cut the logs, branches, stringy cedar bark, etc. into uniform lengths. The separator portion would remove the undersize material (< 2.54 cm) which contains the dirt and water that hog fuel boiler operators find objectionable. This would permit material to be introduced into hog mill conveyor systems without modification and would result in uniform feed to the hog mill. A field test of a very basic system was conducted in the Fall of 1981 in MacMillan Bloedel's Shawnigan Division sortyard to prove the concept. The test established that the concept and benefits were valid but the equipment used was unreliable and productivities and costs could only be estimated (Sinclair 1982).

In 1982 Forestal International and the B.C. Ministry of Forests, through ENFOR contracts P-183 and P-184, mounted a shear, conveyors and a power supply on a trailer to make a reliable, mobile system. This machine processed logging residues at landings in both Coastal and Interior British Columbia. A report on this work has been published (Oakley and Manning 1984). In 1983 FERIC was awarded an ENFOR contract to modify the mobile shear for sortyard waste, to add a separator section and to field test the system.

The objectives of this study were the following:

a. To incorporate the Nicholson Murdie Biomass shear (the concept is proven) into a reliable, pre-production prototype of a complete stationary system, and to establish production capacity and processing costs.

b. To process log sortyard and logging debris into a cleaner, more homogeneous product suitable as feedstock for hogged fuel without modification to the hog mill installation.

c. To report the costs, productivities and energy balance of the separator-shear system.

d. To develop a system for the industry that will be commercially available to reduce petroleum purchases.

The test site chosen was B.C. Forest Products' Shoal Island sortyard. This site was selected because it is one of the larger coastal sortyards (1 000 000 m^3/year) and because this sortyard utilizes its logyard waste as hog fuel. The debris is transported daily to an adjacent pulp mill where it is processed into hog fuel and burned in the mill's cogeneration boiler. The hog mill and conveying systems were designed and built to specifically handle and process sortyard debris.

SYSTEM

Figure 1 is a flow diagram and Figure 2 is a schematic drawing of the separator-shear system. Various components and operations of the system are illustrated in Figure 1 and Figure 2, respectively.

Debris Pile

Logyard waste or debris is continuously swept off of the sortyard's asphalt surface into a pile located in the corner of the sortyard. Approximately 50 units[1] or 115 tonnes of debris are generated each day at Shoal Island. The actual amount varies depending on the species of logs being sorted, the amoung of log bucking and the season of the year. Figure 3 is a picture of the debris pile which is composed of bark, branches, slabs, logs, chunks, etc.

Log loader

A truck-mounted, hydraulic log loader was used to place debris on the infeed conveyor of the shear. This type of log loader can easily select, orient and control the amount of material being fed to the shear to minimize blockages.

Infeed conveyor and shear

The mobile shear (Fig. 4, 5, 6) was the same unit used on previous tests, but the following modifications were made to adapt the unit to handle sortyard debris and to increase productivity:

a. The infeed conveyor was raised 10 cm to match the elevation of the shear's anvil.

b. The outside two flights of the infeed conveyor chain were reversed to centralize the flow of debris in the conveyor.

c. The infeed conveyor's speed was increased 30 percent.

d. The chuting on the infeed conveyor was streamlined to prevent blockages.

e. Rakers were added at the headsprocket to prevent debris carrying over and building up on the sprocket drum.

f. A powered holddown roll was added in the anvil area between the infeed conveyor and the shear to push the debris through the anvil area.

g. The holddown roll, shear and infeed conveyor controls were combined to permit automatic advancing and shearing of the debris. The length of advance of the holddown roll and the infeed conveyor was adjustable.

h. The outfeed portion of the shear's anvil was removed to reduce blockage of debris at the shear.

As in previous tests, the unit was powered by a 6-71 General Motors diesel. However, additional hydraulic pumps and control valves were added to accommodate the additional demands, to provide the automatic control feature, and to power the other conveyors and components.

Intermediate conveyor

The material leaves the shear in surges because the infeed conveyor is stopped while the debris is cut. A conveyor was placed between the shear and the disc separator to smooth the surges. This reduced surge overloading of the disc separator and improved separation efficiency. Steel chains conveyed the material up the conveyor which was 5 m long and 61 cm wide.

Disc separator

A heavy duty disc separator with ten scalloped discs on each of nine shafts was used to separate the undersized, dirty material. It operated at about 75 rpm. Initially, the disc and shaft spacing was incorrect for the size of material requested (less than 2.54 cm). Spacers, welded to the discs, helped, but the disc separator still passed too much undersize material. Also, the spacers re-

[1] One unit = 5.7 m^3 of gravity packed material.

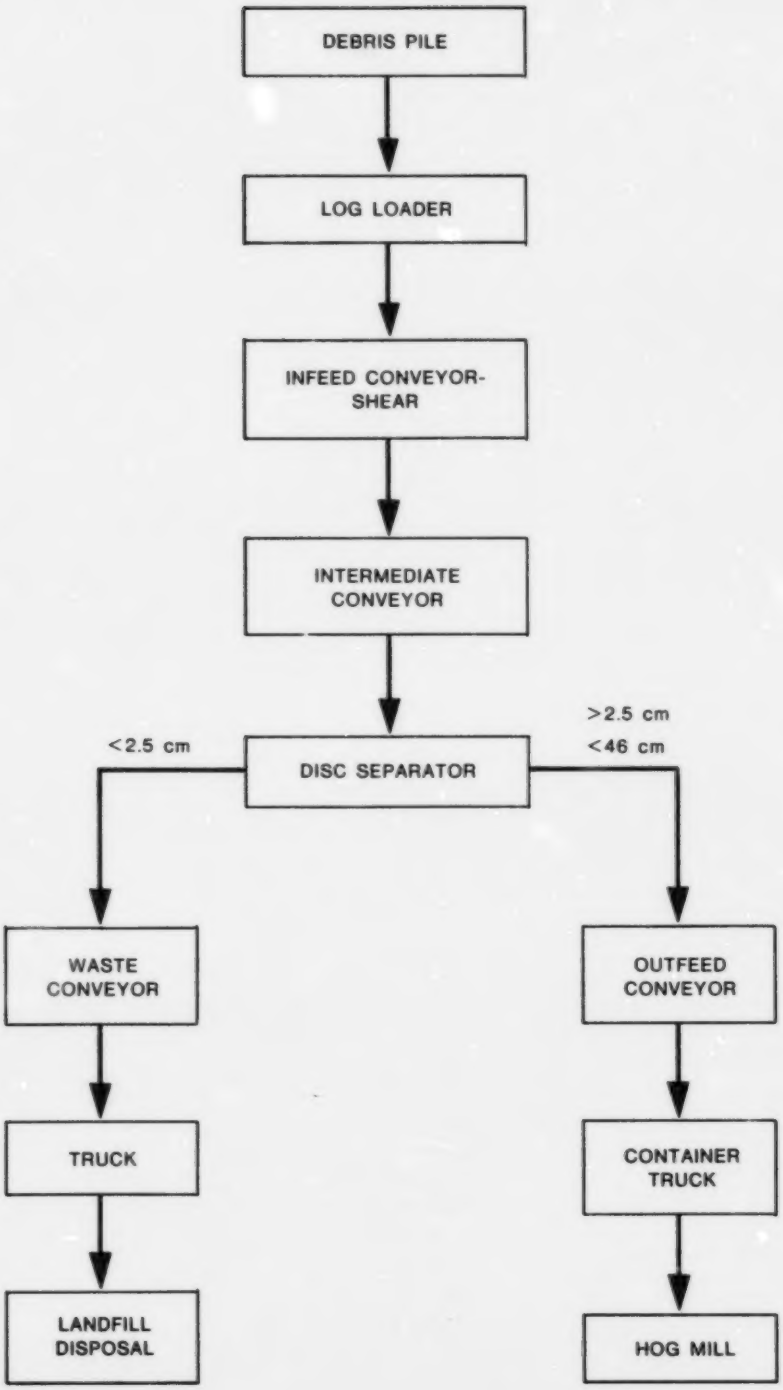

Figure 1. Flow Diagram of Separator-Shear System

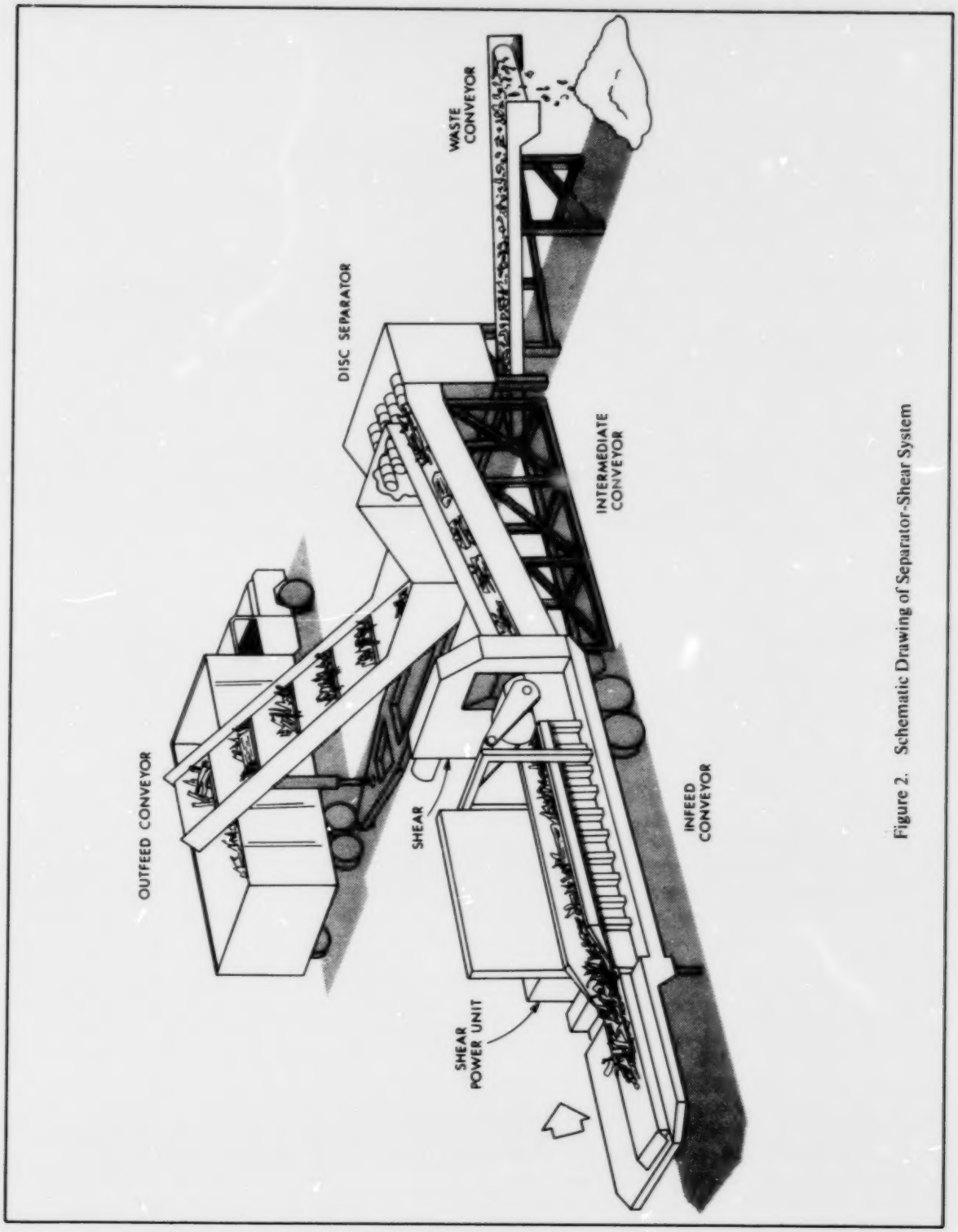

Figure 2. Schematic Drawing of Separator-Shear System

F_ .re 3. Debris Pile

Figure 4. Side View of Separator-Shear

Figure 5. Infeed Conveyor and Holddown Roll

Figure 6. Shear Blade and Outfeed

Figure 7. Logging Residues

Figure 8. Sortyard Debris

Figure 9. Sheared, Separated Sortyard Debris

duced the effective height of the disc scallops which, in turn, reduced material agitation and separation effectiveness. The separator was set at right angles to the intermediate conveyor to minimize the amount of long narrow pieces of debris dropping between the discs. This removed two rolls of discs from effective operation and so reduced the residence time of the material on the separator. Too much oversize material (greater than 2.54 cm) passed through the screen and, too much undersize material was carried over the screen.

Waste conveyor, transport and disposal

Undersize material passed through the separator and onto a 46-cm-wide belt conveyor. The waste fines were discharged from the conveyor into a pile. A small front-end loader periodically loaded the fines into a tandem-axle dump truck for transport to a landfill site.

Outfeed conveyor, transport and hogging

The outfeed conveyor was the same as used in previous tests, but had steel chuting added to the inlet area to prevent material falling onto the ground. Like all the other equipment, it was hydraulically driven. The material was moved up the conveyor by steel flights where it dropped into container trucks or dump trucks. The trucks transported the sheared and separated debris approximately 3 km to one of two hog mills for processing into hog fuel. From time to time, the hog mills would break down and delay time would result.

TEST AND RESULTS

The test was in two parts. In the first part, the system was set up at the Shoal Island sortyard, debugged, and then the logging residues that had been recovered from logging landings in an earlier ENFOR project (Sinclair 1984) were sheared. The biomass consisted primarily of slabs, chunks and logs less than 30 cm in diameter but up to 13 m in length (see Figure 7). It was sheared so the length was nominally less than 46 cm. After shearing, the material was to be transported to the Klockner chipper for processing into hog fuel. Unfortunately, only a few loads could be processed because hog fuel was in surplus at the pulp mill. Productivity was measured by continuous timing methods and all material passed through the separator-shear was weighed. After the logging residues had been processed, the system was disassembled and returned to Nicholson Murdie's shop for the modifications required to process sortyard debris. After the modifications were completed, the system was returned to the sortyard, reassembled and the second part of the test began. Again, productivity was measured using continuous timing methods and all material processed through the system was weighed. In addition, raw sortyard debris, separated sortyard debris (reject material), sheared sortyard debris and hog fuel were sampled to determine size distribution, moisture content, ash content and calorific value. A record was also maintained of the diesel fuel and gasoline consumed by the equipment.

The first part of the test lasted from October 3 to October 14, 1983. The equipment was modified during the period October 17 to December 2, 1983. The second part of the test started on December 7, 1983 and was completed January 19, 1984.

Logging residues

Material Analysis

Two samples each were taken of sheared logging residuals and hog fuel made from sheared material. Analysis indicated the majority of the sheared material was in the 15-30 cm size class, although the shear was set to automatically advance and

cut the logs at 46 cm. Slippage occurred between the feed roll and the log and as a result some logs would not advance the full amount before being sheared. This reduced production and resulted in small pieces than desired.

The hog fuel sizing was concentrated in size classes greater than 28.6 mm, which was not good. The horizontally-fed Klockner chipper used powered holddown rolls to align, hold and feed logs and longer pieces of material into the knives. When sheared pieces of logs that were mainly 15-30 cm long were processed, they went through the chipper unrestrained or sideways, which resulted in poorly sized hog fuel. If the material had been processed in the pulp mill's vertically-fed Gruendler hammer hog, then a better product may have resulted.

System Productivity

During these tests, truck weights and loads were measured and a continuous timing record was made of the system's operation. The results are given in Tables 3 and 4.

Most delay times could be reduced as these tests were done during the break-in period of the system and crew. For example, operators would attempt to process oversize logs which would become blocked in the 76 cm by 76 cm shear opening . Also, some of the hydraulic circuits and components on the shear and separator malfunctioned. If the crew and equipment had a longer break-in period before the tests, then a utilization of 85% could have been achieved.

Based on an eight-hour shift, the separator-shear processed 54.7 tonnes per shift. However, with a more reasonable utilization of 85%, the system should be able to process 66.8 tonnes per eight-hour shift when cutting logging residue to a nominal length of 46 cm. This rate is higher than those achieved in previous trials with the shear on dry logging residues. Also, in light of experience gained in processing the sheared residues in the Klockner chipper, it probably would have been better to shear the material into 92 cm lengths. This would allow double production to 133.6 tonnes per shift on dry logging residues and I feel that this level is obtainable on an operational basis.

Fuel Consumption

The volumes and energy contents of the gasoline and diesel fuel used in the logging residue trial are given in Table 5.

Sortyard debris

Material Analysis

Unprocessed Sortyard Debris — Twenty-four samples of raw sortyard debris (Fig. 8) were analyzed for type and size distribution using a statistical quartering technique. Material less than 7.5 cm was further analyzed for ash and moisture content and particle size distribution. The Williams Classifier was used to determine size distribution of the material less than 7.5 cm. Size and type distribution of the debris are given in below.

The density of the debris averaged 422 kg/m^3 and is higher than normal. Rainy conditions and an observed absence of logs in the debris probably caused this.

The ash and moisture were determined on four samples of the less-than-7.5 cm class of debris. The ash content was 19.5 percent (dry basis).

Separated Sortyard Debris — Twenty four representative samples were taken from the undersize material pile for size distribution analysis. Four samples were analyzed for moisture content and ash content. The ash and moisture contents for this fraction were higher and the density considerably higher than in raw sortyard debris (Table 8).

Although the design specification for size separation on the disc separator was 2.54 cm, it was not built to specification. Consequently, more than 17 percent by weight of the waste fines was oversize and should have gone to the hog mill rather than to landfill disposal.

Sheared Sortyard Debris — Sixteen samples of the sheared sortyard debris were analyzed for size distribution using the statistical quartering technique. The material in the less than 7.5 cm size class was further analyzed using the Williams Classifier (Table 8).The density of the sheared, separated sortyard debris averaged 403 kg/m^3.

Within the class size of less-than-7.5-cm size class there is considerable undersize material which reflects poor performance by the disc separator. This was mainly because the disc separator was operated above its rated capacity of 100 tonnes per shift. Also, the addition of spacers reduced the effective height of the scallops on the discs and thus the vertical agitation caused by the discs.

Figure 9 is a picture of the sheared, separated debris.

Processed, Sheared Sortyard Debris — The sheared debris was transported from the sortyard to a pulp mill where it was processed into hog fuel in either of the two hog mills. One hog mill, the Gruendler, is a vertically-fed, swinging-hammer hog mill and is used primarily to process wood waste from the woodroom. The other hog mill, the Klockner, is a horizontally-fed, drum chipper and was specially installed to process sortyard debris from a variety of log yards.

Seven samples of hog fuel were taken throughout the duration of the tests from the outlet conveyor of the Gruendler hog mill. The samples were analyzed on the Williams Classifier for size distribution and two samples were sent to a commercial laboratory for moisture content, calorific value and ash content determination. The results are shown in Appendix I. The ash content is lower than for raw sortyard debris. The moisture and ash contents are acceptable for hog fuel.

At the request of the pulp mill, most of the material produced during the trials was processed in the Klockner mill. Twenty samples of hog fuel were taken throughout the trials for size distribution analysis. Four of these samples were further analyzed for ash content, moisture content and calorific value. The results are given in Appendix I.

Comparison of the ash content value with that for sortyard debris show that separation has reduced the value. The ash, moisture and calorific values are acceptable for hog fuel.

System Productivity

The separator-shear system was continuously timed to determine productive and non-productive time elements. All truckloads of material were counted and weighed and a record of fuel consumption was maintained. The results are given in Tables 9 and 10.

An improved intermediate conveyor design would reduce debris carryover and blockaged and the delay element "Wait Intermediate Conveyor" would be less. The test achieved a utilization of 86 percent and in normal operation it would likely be this or slightly higher.

Based on an eight-hour shift, the separator-shear processed 211 tonnes of debris per shift. At this rate, the system can process all the debris generated by a sortyard handling 10 550 m^3 of logs per day.

Thirty-three percent of the debris passed through the separator and was considered waste because of the high dirt and moisture content. In a commercial application, the separator would be modified so that the waste fraction would likely be 20-25% by weight.

Fuel Consumption

The volumes and energy contents of the gasoline and diesel fuel used during the tests on sortyard debris are given in Table 11.

Fuel consumption per tonne for processing was comparable between tests as was expected. Fuel consumption per tonne for transportation was higher for logging residues because less weight per load was carried and transportation distances were larger.

ECONOMICS

The results of the trial on logging residues are excluded because of the break-in problems and the shortness of the trial. Only the results from the sortyard debris trials are included in the economic analysis.

An estimate of the economics of the separator-shear system, based on the results of the field trials is:

Production Estimate

Field Test Production/Shift	211 tonnes
Estimated Operational Utilization	86%
Estimated Operational Production/Shift	211 tonnes
Estimated Weight/Shift Hog Fuel (80%)	167 tonnes
Estimated Weight/Shift Waste (20%)	41 tonnes

Cost Estimate

Ownership Costs

Capital Costs — The capital cost of a stationary separator-shear system, complete with a hydraulic log loader, is estimated at $450 000 installed. The annual costs associated with the capital costs are:

Depreciation — 10 year life, no residual value	$45 000
Insurance @ 1% of average value	2 250
TOTAL	$47 250

Based on a 200 day year for a log sortyard operation, the ownership cost converts to approximately $240 per shift.

Interest Costs — Interest costs are calculated 15% of the average capital investment or $33 750 per year.[2] For a 200 day year this becomes $170 per shift.

[2] Calculated as $\frac{(\$450\,000 + \$0)}{2} \times 0.15 = \$33\,750/\text{year}$

[3] Costs per tonne reflect the differences in density of the various types of material.

Operating Costs

The operating and maintenance costs per shift of an electrically-powered, stationary separator-shear system with a diesel powered log loader, is estimated as:

System Operator	$200
Ground Man	168
Chainsaw, Misc. Supplies	80
Diesel Fuel & Electricity	80
Repairs and Maintenance	200
TOTAL	$728/shift

Production Costs

The total cost/shift of the separator-shear system is obtained by adding the capital, interest and operating costs and is estimated at $1140. This results in an estimated production cost of $5.40 per tonne or $12.90 per unit. Interest costs contribute $0.80 per tonne to the total. The production cost is less than the average costs of $17.00 per unit experienced for landfill disposal at a site 5-10 km from the sortyard.

Transportation and Hogging Costs

To examine the total economics, the costs of transporting the sheared material to a hog mill, the disposal costs for the fines and the hogging costs have to be included. The transportation costs will vary with distance and the type of carrier, but for the purposes of this analysis, it is assumed that the hog mill is 60 km away and an eight unit capacity truck and trailer are used. With this distance and carrier, the transportation costs will be $15.80 per unit or $7.65 per tonne.[3] Disposal costs are assumed to be average costs of $17.00 per unit or $4.95 per tonne. Similarly, hogging costs are estimated at $7.50 per unit or $3.20 per tonne. The transportation, disposal and hogging costs are summarized as:

Transportation to hog mill	$7.65/tonne
Disposal	$4.95/tonne
Hogging	$3.20/tonne

Savings

The material that is separated and sheared will no longer require landfill disposal and a saving will thus result. Also, once the material is hogged and burned in the boiler, a saving in oil purchases will occur. The amount of the oil purchase saving will mainly depend on the moisture content and thus the net heating value of the hog fuel. Appendix II gives the calculation used to determine the oil saving for these field trials. These two annual savings are calculated as:

Debris Disposal savings 33 400 x $8.20	$273 800
Oil savings 33 400 x $17.00	567 800
	$841 600

Total System Costs and Benefits

The total annual system costs and benefits of a separator-shear system, operating in a sortyard with a landfill site 5-10 km distant and a pulp mill with a hog mill 60 km distant, are estimated as:

Annual Production	41 600 tonnes
Separated & Sheared Production	33 400 tonnes
Waste Production	8 200 tonnes
Processing Cost (41 600 × $5.40	$224 640
Transport to Hogmill (33 400 × $7.65)	255 510
Waste Disposal (8 200 × $4.95)	40 950
Hogging Costs (33 400 × $4.20)	140 280
Total Costs	$661 020
Debris Disposal Savings	273 800
Oil Savings	567 800
Total Savings	$841 000
Net Benefit	$180 580
Capital Investment	$450 000
Payback	2.5 years

If a company has a demand for hog fuel and does not wish to install a specialized hog mill and conveyor system for sortyard waste then the separator shear is economicallly attractive .

CONCLUSIONS

The Nicholson biomass shear was made into a reliable, precommercial production prototype and achieved 86 percent utilization in field tests. A utilization rate of 86 percent or higher is likely on an operating basis.

The separator-shear system processed sortyard debris at a rate of 211 tonnes per eight-hour shift during field trials and this or better is achievable on an operational basis. At this rate, the operating, maintenance and ownership costs of the system are $5.40 per tonne of debris processed. This is less than conventional disposal costs of $7.00 to $7.50 per tonne.

The economics of a system which processed sortyard debris, transports the sheared material to a hog mill 60 km distant, transports the waste fines to a landfill 5-20 km distant and hogs the sheared debris into hog fuel, are summarized in Table 12. Transportation costs to the hog mill are significant and if the hog mill is closer to the yard the economics improve. Also, the moisture content of the hog fuel has a significant effect on economics. A payback of 2.5 years is attractive and should ensure the commercial acceptance of this system.

Processing sortyard debris in the separator-shear system improved its value as feedstock for hogged fuel. Separation reduced ash and moisture content and shearing reduced the range of sizes. Oversize material was eliminated and the sheared material flowed better in the hog mill's conveyors and through the hog mill.

In a short trial, dry logging residues were processed through the separator-shear. Although set to shear a nominal length of 46 cm, slippage between the feed rolls and the residue resulted in the majority of the pieces being 15 to 30 cm long. Field test productivity was 54.7 tonnes per shift. Operational utilization of 85 percent will result in a production rate of 66.8 tonnes per shift and, if the material is sheared to a nominal 92 cm length for drum-chipper hog mills, the production rate could reach 133.6 tonnes per shift.

There are two modifications that will be necessary in a commercial model. The first is to include a scanning device at the outlet of the shear to

ensure that the required length of debris has protruded through the shear opening before it is cut. The second is to design the disc separator so that the number of shafts, the rotation speed of the discs and the disc and shaft spacing is adequate to give efficient separation at the production rate of the system.

Energy consumption averaged 110.6 Mj per tonne of material processed, both for dry logging residues and sortyard debris. Energy comsumed in transportation varied from 49.5 Mj to 124.9 Mj and reflected differences in transportation distances and load size. The net heating value of the hog fuel produced from sortyard debris was 4580 Mj per tonne.

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Table 1. Type and size distribution of sheared logging residues

Size Class	Type of Material Distribution	Percentage Weight
> 100 cm	Wood	—
60-100 cm	Wood	13.13
30-60 cm	Wood	5.74
15-30 cm	Wood	70.49
7.5-15 cm	Woody Material	10.64
< 7.5 cm	Woody Material	—
	Total	100.00

Table 2. Size distribution of hog fuel from logging residues — Klockner chipper

Size Class	Percentage Weight Distribution
> 28.6 mm	39.63
22.2 mm – 28.6 mm	16.04
15.9 mm – 22.2 mm	14.02
9.5 mm – 15.9 mm	12.41
4.8 mm – 9.5 mm	12.25
< 4.8 mm	5.65
Total	100.00

Table 3. Time study results — logging residues

	Time	
	Hours	%
Total Time	31.2	100.0
Productive Time	21.68	69.7
Non-Productive Time	9.44	30.3
Non-Productive Time Distribution		
Delays —		
Wait Trucks	0.70	2.2
Wait Loader	0.10	0.3
Wait Infeed Conveyor/Shear	1.60	5.1
Wait Disc Separator	0.07	0.2
Demonstration Time	1.20	3.9
Mechanical Breakdown-Shear	1.35	4.3
Mechanical Breakdown-Separator	4.42	14.2
Sub-Total	9.44	30.3

Table 4. Logging residues processed

Total Residues Processed (tonnes)	213
Residue Processed/Total Time (t/h)	6.84
Residue Processed/Productive Time (t/h)	9.82

	Loads
2.5 Unit Capacity Trucks	10
6 Unit Capacity Containers	17
8 Unit Capacity Trailer	8
Estimated Volume of Sheared Residues (units)	191
Nominal Load Density (tonnes/unit)	1.12

Table 5. Fuel consumption — logging residue tests

	Fuel Consumption
	litres
Processing	
Separator-Shear (diesel)	432
Log Loader (diesel)	236
	668
Transportation	
Container Truck (diesel)	464
Dump Truck (gasoline)	318
Net Heating Values	(Mj/l)
Diesel	35.6
Gasoline	31.7
Energy Consumption/Tonne Processed	(Mj/t)
Processing	111.6
Transportation	124.9

Table 6. Type and size distribution of unprocessed sortyard debris

Size Class	Type of Material	Percentage Weight Distribution
> 100 cm	Wood	2.04
	Cedar Bark	1.46
	Other Bark	–
	Branches	0.42
	Non-wood	–
	Class Total:	3.93
60 – 100 cm	Wood	1.79
	Cedar Bark	1.46
	Other Bark	0.05
	Branches	0.20
	Non-wood	–
	Class Total	3.50
30 – 60 cm	Wood	1.56
	Cedar Bark	2.43
	Other Bark	1.73
	Branches	0.31
	Non-wood	–
	Class Total	6.03
15 – 30 cm	Woody material	11.65
	Non-wood	–
	Class Total	11.65
7.5 – 15 cm	Woody material	8.32
	Non-wood	–
	Class Total	8.32
< 7.5 cm*	> 28.6 mm	12.65
	22.2 mm – 28.6 mm	7.19
	15.9 mm – 22.2 mm	9.79
	9.5 mm – 15.9 mm	16.78
	4.8 mm – 9.5 mm	13.91
	< 4.8 mm	6.19
	Class Total:	66.57
	Grand Total	100.0

* Non-wood material is not reported in this size class as it is too fine to segregate. This size class is tested for ash content and moisture content.

Table 7. Size distribution, ash content and moisture content of material sized to less than 2.54 cm

Size Class	Percentage Weight Distribution
> 28.6 mm	17.6
22.2 mm – 28.6 mm	11.7
15.9 mm – 22.2 mm	14.4
9.5 mm – 15.9 mm	29.2
4.8 mm – 9.5 mm	20.4
< 4.8 mm	6.7
Ash Content (Dry Basis)	26.3
Moisture Content (Wet Basis)	62.8
Density	609 kg/m^3

Table 8. Size distribution of sheared, separated sortyard debris

Size Class	Type of Material	Percentage Weight Distribution
> 100 cm	White wood	0.08
	Cedar bark	0.36
	Other bark	—
	Branches	0.19
	Non-wood	—
	Class Total	0.63
60 — 100 cm	White wood	3.25
	Cedar bark	1.94
	Other bark	—
	Branches	0.64
	Non-wood	—
	Class total	5.83
30 — 60 cm	White wood	2.15
	Cedar bark	4.54
	Other bark	1.56
	Branches	0.63
	Non-wood	—
	Class Total	8.88
15 — 30 cm	Woody material	10.60
	Non-wood	—
	Class Total	10.60
7.5 — 15 cm	Woody material	9.42
	Non-wood	—
	Class Total	9.42
< 7.5 cm	> 28.6 mm	20.07
	22.2 mm — 28.6 mm	8.47
	15.9 mm — 22.2 mm	10.13
	9.5 mm — 15.9 mm	13.59
	4.8 mm — 9.5 mm	7.20
	< 4.8 mm	5.16
	Class Total	64.62
	Grand Total	100.0

Table 9. Time study results — separator shear system

	Time	
	Hours	%
Total Time	140.21	100.0
Productive Time	120.52	86.0
Non-Productive Time	19.69	14.0
Non-Productive Distribution		
Wait Trucks	4.83	3.4
Wait Hog Mill	3.52	86.0
Wait Log Loader	0.45	0.3
Wait Infeed Conveyor/Shear	1.43	1.0
Wait Intermediate Conveyor	4.08	2.9
Wait Disc Separator	1.03	0.7
Wait Outfeed Conveyor	0.78	0.6
Wait Waste Conveyor	—	—
Shear Mechanically Down	3.23	2.3
Other	0.33	0.2
Subtotal	19.69	14.0

Table 10. Debris processed

Total Debris Processed	3 693
Debris Processed/Total time (t/h)	26.34
Debris Processed/Productive Time (t/h)	30.65

Material	Loads		
	2.5 Unit* Capacity Truck	6 Unit Capacity Container	8 unit Capacity Trailer
Sheared Debris	173	118	6
Waste Fines	143	—	—

	Units
Sheared Debris	1 188.5
Waste Fines	357.5

	Tonnes
Sheared Debris	2 459.3
Waste Fines	1 233.6

Nominal Load Density (t/unit)	2.39

* 1 unit = 5.7 m^3 of gravity packed material.

Table 11. Fuel consumption — sortyard debris tests

	Fuel Consumption (litres)
Processing	
Separator-Shear (diesel)	7 275
Log-loader (diesel)	2 270
Front-end Loader (diesel)	1 820
	11 365
Transportation	
Container Truck (diesel)	1 820
Dump Trucks (2) (gasoline)	3 640
Front-end Loader (diesel)	455
Net Heating Values	(Mj/l)
Diesel	35.6
Gasoline	31.7
Energy Consumption/Tonne Processed	(Mj/t)
Processing	109.6
Transportation	49.5
Heating Value of Hog Fuel	(Mj/t)
Gross Heating Value	18 452
Net Heating Value	4 580

Table 12. Summary of economics

Hog Fuel Production	33 400 tonnes
Waste Production	8 200 tonnes
Separating-Shearing Cost	$224 640/year
Transport to Hog Mill Cost	255 510/year
Waste Disposal Cost	40 590/year
Hogging Costs	140 280/year
Total costs	$661 020/year
Debris Disposal Savings	273 800/year
Oil Savings	567 800/year
Total savings	$841 600/year
Net Benefit	$180 580/year
Capital Investment In System	$450 000
Payback	2.5 years

APPENDIX I

ANALYSIS OF HOGGED FUEL – GRUENDLER HOG MILL KLOCKNER CHIPPER

Table I-1. Analysis of hogged fuel – Gruendler hammer hog mill.

Size Class	Percentage Weight Distribution
> 28.6 mm	2.95
22.2 mm – 28.6 mm	4.45
15.9 mm – 22.2 mm	12.46
9.5 mm – 15.9 mm	20.15
4.8 mm – 9.5 mm	35.31
< 4.8 mm	24.68
No. of Samples for Size Analysis	7
Ash Content (Dry Basis)	8.4
Moisture Content (Wet Basis)	58.9
Calorific Value – Gross	19 820 kJ/kg
Density	440 kg/m^3

Table I-2. Analysis of hogged fuel - Klockner chipper.

Size Class	Percentage Weight Distribution
> 28.6 mm	19.24
22.2 mm – 28.6 mm	13.35
15.9 mm – 22.2 mm	15.06
9.5 mm – 15.9 mm	30.82
4.8 mm – 9.5 mm	15.08
< 4.8 mm	6.45
No. of Samples for Size Analysis	20
Ash Content (Dry Basis)	16.4%
Moisture Content (Wet Basis)	64.1%
Calorific Value (Gross)	18 452 kJ/kg
Density	408 kg/m^3

APPENDIX II

OIL REPLACEMENT VALUE

1. Net or As-Fired Heating Value

The equation used to determine the net or as-fired heating value of a kilogram of debris is:

$$Q - (E - W - T - S)(1 - A)$$

Where:

Q = as-fired or net heating value (kilojoules per kilogram of wet debris).

E = bone dry heating value (kilojoules per kilogram of dry debris).

W = heat loss due to heating the water formed from the combustion of hydrogen in the debris (kilojoules per kilogram of dry debris).

W = 0.54 (2442).

0.54 = 0.54 kilograms of water is formed from hydrogen in the debris for every bone dry kilogram of debris burned.

2442 = heat required to evaporate a kilogram of water (kilojoules per kilogram).

T = heat loss due to heating the water present as moisture in the debris (kilojoules per kilogram of dry debris).

T = B (2442).

B = moisture content (dry basis) per kilogram of debris.

S = heat loss due to heating the dirt in the debris (kilojoules per kilogram of dry debris).

$S = 0.84 \times D \times (t1 - t2)$

0.84 = specific heat of sand (kJ/kg degrees C).

D = kilograms ash per kilogram of dry debris.

D = 0.164 (Table III-2 in Report).

t1 = temperature at which ash leaves the furnace of the boiler (degrees C).

t1 = 204 degrees C

t2 = ambient temperature (degrees C)

t2 = 15.6 degrees C

A = moisture content (wet basis) per kilogram of debris.

The result of applying the values in Table III-2 of this report to the equation is:

$Q = (18452) - (0.54 \times 2442) - (1.786 \times 2442) - (0.84 \times 0.084)(204 - 15.6))(1 - .641)$

= 4580 kilojoules/kilogram of debris (wet basis).

2. Oil Replacement Value

The gross value of hogged fuel in a boilerhouse can be estimated by calculating the value of the other fuels replaced by the hogged fuel. Then to get a net value, adjustments for differences in operating costs, capital costs and boiler efficiencies have to be made.

The following calculation to determine the oil replacement value of hogged fuel is based on hogged fuel replacing bunker C oil. It takes into account the difference in combustion efficiencies between hogged fuel-fired and oil-fired boilers but not capital and operating costs. The calculation is:

Cost of bunker C oil = $410/million kilojoules (at $25.40/barrel).

Kilograms of debris required per million kilojoules

$$= \frac{1\,000\,000 \text{ kJ}}{4580 \text{ kJ/kg}} = 218 \text{ kg}$$

Kilograms of debris per unit of debris

$$= 5.7 \text{ m}^3 \times 440 \text{ kg/m}^3$$

$$= 2508 \text{ kilograms}$$

Millions of kJ per unit of debris

$$= \frac{2508 \text{ kilograms}}{218 \text{ kilograms}} = 11.5 \text{ million kJ}$$

Combustion efficiency of oil-fired boiler = 0.83%
Combustion efficiency of hogged fuel-fired boiler = 0.75%
Oil replacement value of debris

$$= 11.5 \times \$4.10 \times \frac{0.75}{0.83}$$

$$= 42.61 \text{ per unit of debris}$$
$$= \$17.00 \text{ per tonne of debris}$$

In terms of oil replaced, this is the value of a unit or tonne of hogged fuel before the additional operating and capital costs of burning hogged fuel have been considered.

The annual production of 33 400 tonnes of hog fuel will replace $17.00/tonne × 33 400 = $567 800 of bunker C oil.

POOR

QUALITY

ORIGINAL